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Small – Signal Model of Series – Parallel Resonant DC-DC Converter with Capacitive Output Filter

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Abstract

This paper presents a small-signal model of the series-parallel resonant DC-DC converter with capacitive output filter. This model is based on generalized averaging method. It simplifies the controller design task for resonant converter. Simulations are used to verify the accuracy of the small-signal model.

Keywords: DC-DC converter; Resonant converter; Small-signal model

1. Introduction

The series-parallel resonant DC-DC converter (SPRC) is a popular configuration as it combines the advantages of the series and the parallel converter while reducing their drawbacks. The structure of the full-bridge SPRC with capacitive output filter is shown in Fig. 1. However, the design of resonant converters is complicated due to the large number of operating states occurring within a pulse period. In addition, the controller design is complicated because the small-signal transfer function is dependent on the operating point of the converter. Many controller design tasks are performed by trial and error. Thus, the setting of the controller parameters can take a long time until a robust set of parameters are found [1].

This paper presents a small-signal model of the SPRC with capacitive output filter. Initially, the converter power circuit is described. Based on generalized averaging method [2], the transient and steady-state behavior is described. Finally, simulations are used to verify the accuracy of the small-signal model.

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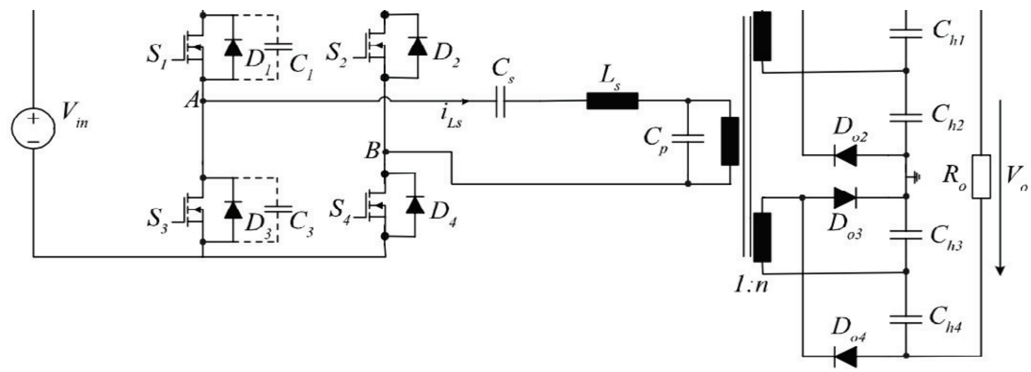


Fig. 1. Full-bridge series-parallel resonant DC-DC converter with capacitive output filter.

2. Converter Power Circuit Description

To simplify the analysis, all output quantities are referred to the primary side of the transformer and the following assumptions are used in this paper.

1) The switches, diodes, inductors and capacitors used are ideal.
2) The magnetizing inductance of the transformer is neglected.
3) The capacitors C_1, C_3 are not included in the analysis.
4) The supplied voltage, V_{in} is constant and has no ripple.
5) The load is a pure resistance.

A simplified converter circuit is shown in Fig. 2 : $V_{o'} = \frac{V_0}{2n}$, $I_{o'} = I_o \cdot 2n$ and $R_{o'} = \frac{R_o}{4n^2}$ where n is the transformer turns ratio. Time behavior of this simplified converter circuit within a pulse period is shown in Fig. 3.

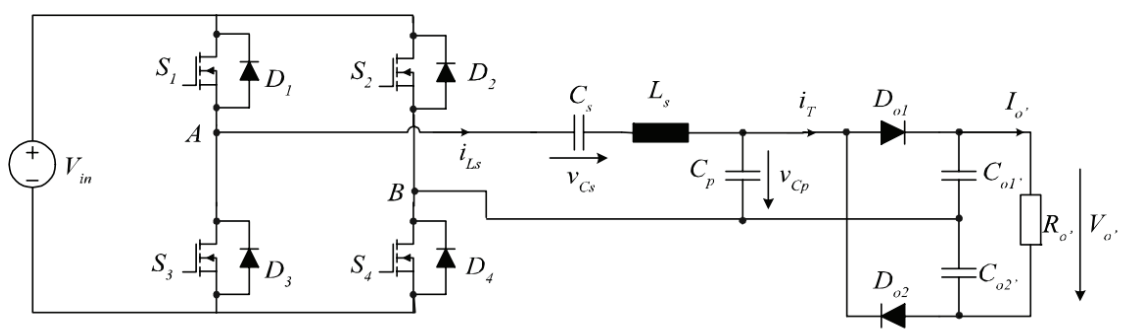


Fig. 2. Simplified SPRC circuit.

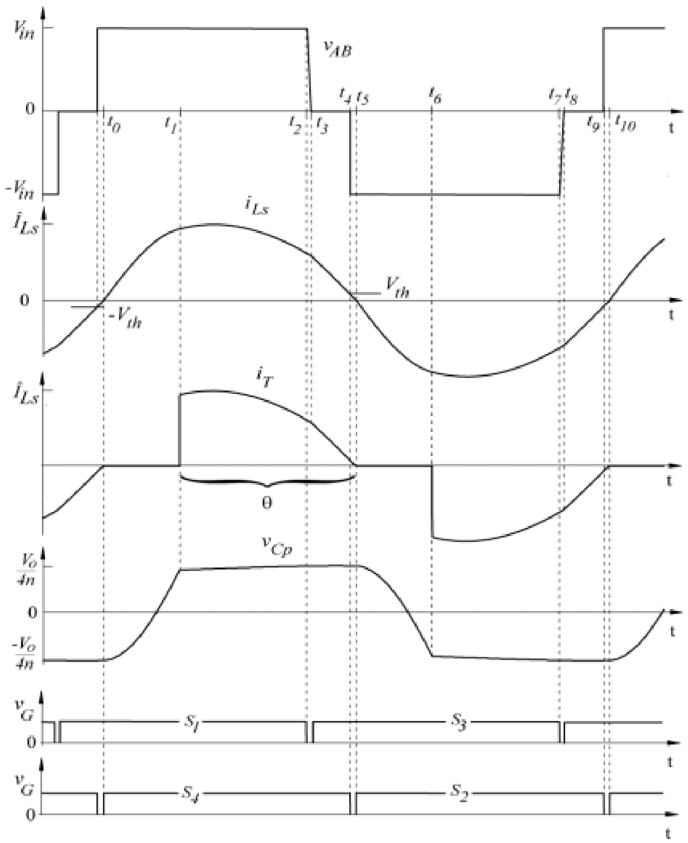


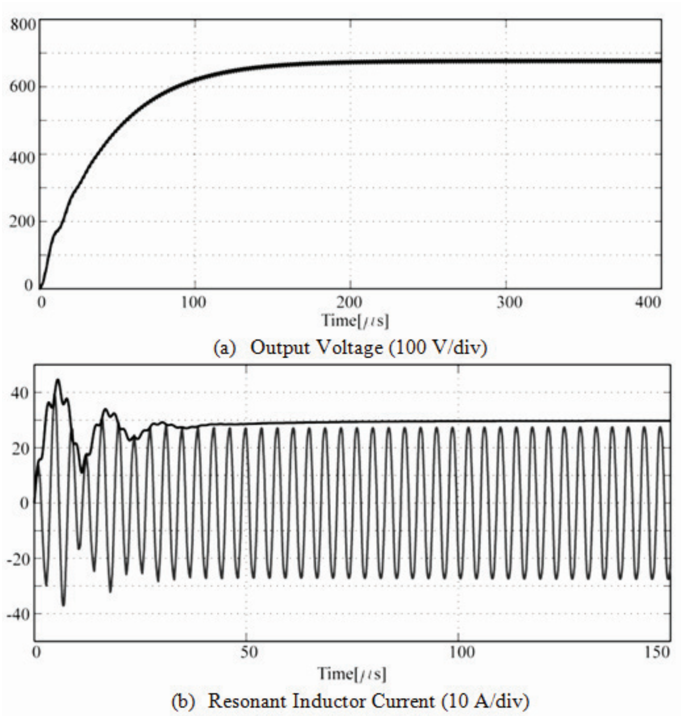
Fig. 3 Time behavior characteristic within a pulse period ($t_0 - t_{10}$).

3. Generalized Averaging Method

Compared to the state-space averaging method, the generalized averaging method can describe arbitrary types of waveforms [2]. It is based on a time-dependent Fourier series representation for a sliding window of a given waveform. The procedure to determine the dynamical model includes two steps. First, one describes the instantaneous switched variables with a standard state-space description. Afterward the state space equations are averaged using complex Fourier series. Second, the averaged model will be linearized around an operating point in order to obtain the small-signal model of the simplified SPRC. Both the generalized averaging model and small signal model of the simplified SPRC are derived from [3].

4. Simulation Results

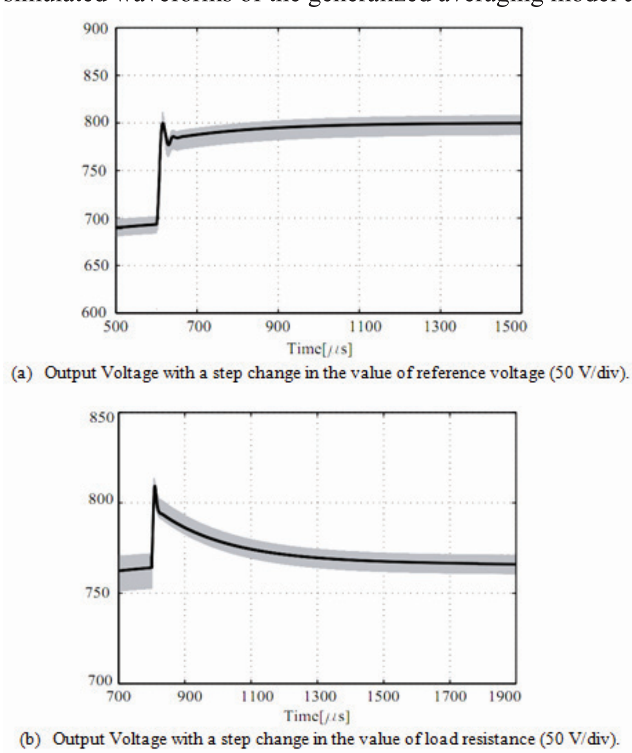
The parameters used in the simulation are as follows: $V_{o'}$ = 767 V, P_o = 4.6 kW, D = 0.752, f_s = 253 kHz and $R_{o'}$ = 128 Ω. The simulation results in the generalized averaging model are shown in Fig. 4. The results show that the correspondence between the waveforms obtained with the model and with the simulated circuit is excellent. The accuracy of the small-signal model is verified using step response both in the value of reference voltage and in the value of the load resistance as shown in Fig. 5. The results show that the waveforms both of the small-signal model and of the circuit are similar. Therefore, this small-signal model is a helpful tool for the control design.



(a) Output Voltage (100 V/div)

(b) Resonant Inductor Current (10 A/div)

Fig. 4 Comparison between simulated waveforms of the generalized averaging model and of the circuit.



(a) Output Voltage with a step change in the value of reference voltage (50 V/div).

(b) Output Voltage with a step change in the value of load resistance (50 V/div).

Fig. 5: Comparison between step response of the small-signal model and of the circuit.

5. Conclusion

The small-signal model is derived for series-parallel resonant converter with capacitive output filter using the generalized averaging method. From this model, it is very easy and quick to know electrical magnitudes with an excellent accuracy. It also simplifies the controller design task for resonant converter.

References

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